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ABSTRACT

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Using the Alouette I topside ionograms for equatorial latitudes for the period from September 1964 to February 1965, the diurnal behavior of topside Spread F and its association with magnetic activity has been studied. It is found that there is a negative correlation between the occurrence of topside Spread F and K_p indices. From a comparison of Spread F below hmF_2 as observed from the Huancayo bottomside ionograms and the topside Spread F at the same latitude, it is found that, besides the general similarity in their diurnal behavior, the onset of Spread F is earlier in the bottomside compared to that in the topside, and that the phenomenon decays later in the topside than in the bottomside. These results are examined in the light of current theories of Spread F and a qualitative explanation is suggested for the persistence of topside Spread F in the morning hours.

Author

INTRODUCTION

The launching of the topside sounder satellite Alouette I in September, 1962 (Warren,1962) opened new means of studying the topside

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ionosphere. The Alouette I satellite moves in a very nearly circular orbit at an altitude of about 1000 Km and an orbital inclination of about 80^{o} to the equator. Topside ionograms are recorded for about 12 minutes at 18 second intervals on command from ground telemetry and command stations. The phenomenon of Spread F as it appears in the topside ionosphere can be studied using the Alouette I topside ionograms (Petrie, 1963; Calvert and Schmid, 1964). Calvert and Schmid (1964) have interpreted the Spread F configurations appearing on the topside ionograms as arising due to (1) aspect - sensitive scattering by thin magnetic-field-aligned irregularities, (2) ducting along broad irregularities and (3) refraction within large scale reductions in electron density. This paper presents the results of a study of topside Spread F at equatorial latitudes. A comparison between the behavior of Spread F in the topside and bottomside is also made.

ANALYSIS OF TOPSIDE SPREAD F

The topside ionograms studied in the present investigation were recorded at the Quito, Ecuador, command and telemetry station. The observations analyzed cover the period from September 15, 1964 to February 17, 1965. The ionograms are examined for the presence or absence of Spread F. During the period of observation, the occurrences of the Spread F configurations due to ducting along broad irregularities and due to refraction within large scale reductions of electron density, as classified by Calvert and Schmid (1964) are very few. Thus, the results presented here correspond mainly to the Spread F configurations due to aspect-sensitive scattering by thin field-aligned irregularities.

The percentage occurrence of Spread F for each hourly interval is computed for latitude intervals of 4^{o}, from 12^{o}S to 16^{o}N geomagnetic latitude. The diurnal variation of the percentage occurrence of topside Spread F is presented in Figs. 1a and b for different latitude ranges. The error flags at each point indicate the 75 percent confidence interval calculated using the t-distribution (Li, 1964). Smooth curves are drawn through the observations to represent the general diurnal behavior of topside Spread F. The general characteristics of these curves are as follows:

1. The topside Spread F is mainly a nighttime phenomenon at equatorial latitudes.
2. The diurnal behavior is similar in the northern and southern latitudes around the geomagnetic equator.
3. The onset of Spread F takes place, generally, between 2000 hours and 2100 hours LMT.
4. The percentage occurrence rises sharply to its maximum and reaches its maximum shortly after midnight.
5. There is a sharp fall in the percentage occurrence of Spread F after 0500 hours LMT and Spread F persists with very much reduced occurrence in the morning hours.

Comparing the above results with those reported by Calvert and Schmid (1964) for the period between September 1962 and January 1963, it is found that there is a general agreement between the two.

In order to study the latitudinal distribution of topside Spread F at equatorial latitudes, the total percentage occurrences are plotted against geographic, geomagnetic and dip latitudes as shown in Figs. 2a and 2b and 2c respectively. It can be seen from these figures that the distribution is symmetrical only about either the geomagnetic or dip equator, suggesting a magnetic control of the phenomenon. At the longitude range under consideration (around 75°W), the geomagnetic and dip equators almost coincide and hence, at equatorial latitudes, one may expect similar distribution with either latitudes as observed here. Singleton (1960) studying the geomorphology of bottomside

Spread F reported that a distribution that is symmetrical everywhere can be obtained only in relation to the geomagnetic equator, while in a limited region around the equator, a distribution in terms of dip also appears to be symmetric. This indicates that the latitudinal distribution of Spread F in the region around the equator is similar in the topside and bottomside F region.

With a view to study the effect of magnetic activity on the occurrence of topside Spread F, the data for the whole latitude range under consideration is grouped according to the corresponding value of the 3 hourly planetary magnetic index K_p and the percentage occurrence for each value of K_p is calculated and plotted as shown in Fig. 3. It should be noted that the K_p scale goes only up to 4, since the period of analysis corresponds to a time near the minimum of solar activity. From Fig. 3 it can be seen that there is a negative correlation between the topside Spread F and magnetic activity as represented by the K_p indices. Calvert and Schmid (1964) reported a weak negative correlation between the topside Spread F at equatorial latitudes due to thin field-aligned irregularities and K_p index. The present finding is in general agreement with that of Calvert and Schmid. It is interesting to note that the bottomside Spread F at equatorial latitudes also shows negative correlation with magnetic activity (Lyon et.al., 1958; Shimazaki, 1959; Rao and Rao, 1961; Krishnamurthy and Rao, 1963). Thus, it can be concluded that the topside and bottomside Spread F at equatorial latitudes behave in the same manner as regards their association with magnetic activity.

COMPARISON WITH BOTTOMSIDE SPREAD F

With a view to compare the diurnal behavior of topside Spread F with that of the bottomside Spread F at the same location and for the same period of observation the bottomside ionograms of Huancayo (12^{o}S Geograph. Lat; 75^{o}W; 0.6^{o}S geomagn. Lat.) taken every 15 minutes during the period from September 15, 1964 to February 17, 1965 are examined for the occurrence of Spread F. The percentage occurrence of Spread F for each hourly interval is obtained and plotted against the local mean time as shown in Fig. 4. In the same figure, the diurnal behavior of the topside Spread F is shown, for the latitude range 0-2^{o}S geomag. lat., which covers the geomagnetic latitude of Huancayo (0.6^{o}S). It should be noted here that the longitudes of the locations of topside observations are around 75^{o}W which is the longitude of Huancayo. Here, we are comparing the Spread F as seen above and below hmF_2 effectively at the same location.

It can be seen from Fig. 4, that the average diurnal behaviors of topside and bottomside Spread F are similar, but for some minor, yet, important differences. The onset of Spread F in the topside is delayed by about 2 hours compared to that in the bottomside. Also, in the bottomside, Spread F disappears soon after ground sunrise, whereas in the topside, Spread F persists in the morning hours, with much reduced percentage occurrence. Thus, it looks as though the whole diurnal curve of topside Spread F is shifted in time with respect to that of bottomside Spread F. Of course, the essential feature of the diurnal behavior of both topside and bottomside Spread F is that they are mainly nocturnal.

To make a direct comparison, instead of the average behavior, between topside and bottomside Spread F, simultaneous observations (within about 8 minutes time difference) are chosen in which Spread F is present at least on one side of hmF_2 and are tabulated in Table 1. The presence of Spread F is indicated by an "x" mark and the absence by a dash.

This table shows that Spread F is present in the topside, a greater number of times than in the bottomside. In other words, the irregularities causing Spread F are more frequent in the topside region than in the region below. The differences in occurrence of Spread F in the topside and bottomside are significant especially in the onset and decay periods as also indicated by the diurnal curves of Fig. 4. In the analysis of bottomside ionograms of Huancayo, it is found that, at, and shortly after the onset of Spread F, the phenomenon, generally, is confined mainly to the low frequency side of the ionogram or bottom part of the F region and then covers the whole frequency range. Thus, in such a case, it can be expected that Spread F may not be present in the topside region at and shortly after the time of onset of Spread F in the bottomside. This also suggests that the mechanism of production of irregularities causing Spread F in the bottomside and topside may not be the same. It is interesting to note here that Briggs (1964) from direct comparison of radio star scintillations observed at Cambridge (52^{O}N, 0^{O}E) and bottomside Spread F at Slough (51.5^{O}N, 1^{O}W) reported that there are occasions of occurrence of scintillations when there is no Spread F observed in the bottomside ionograms and suggested that there must be irregularities above the maximum of the F region which are unobservable by ground based sounders. Taking for granted that the irregularities causing Spread F and radio star scintillations are the same, the observations of Briggs, though for a high latitude station are in agreement with the result from Table 1, that the irregularities are more frequent in the topside region than in the bottomside region. Unfortunately, no reports on direct comparison of simultaneous observations of radio star scintillations and Spread F at equatorial latitudes are available in the literature.

DISCUSSION

The comparison between topside and bottomside Spread F presented in the previous section brought out the general similarity in their diurnal characteristics and their association with magnetic activity, besides some differences, namely, Spread F

TABLE 1

OCCURRENCES OF TOPSIDE AND BOTTOMSIDE SPREAD F

Date	Local Mean Time	Topside	Bottomside	Date	Local Mean Time	Topside	Bottomside
9/21/64	23.7	x	x	12/11/64	0.9	x	x
9/23/64	23.4	x	x	12/12/64	0.8	x	x
9/24/64	23.3	x	x	12/19/64	23.8	x	x
9/25/64	23.2	x	-	1/7/65	21.3	x	x
9/26/64	23.0	x	x	1/9/65	21.0	x	x
9/27/64	10.7	x	-	1/24/65	7.4	x	-
9/30/64	22.5	-	x	2/1/65	6.3	x	-
10/2/64	22.3	x	-	2/4/65	6.0	x	-
10/5/64	21.9	x	-	2/16/65	4.4	x	x
10/10/64	21.2	-	x				
10/12/64	21.0	x	x				
10/13/64	8.6	x	-				
10/14/64	20.7	x	x				
10/15/64	20.6	-	x				
10/20/64	19.9	-	x				
10/23/64	19.5	-	x				
10/27/64	6.8	x	-				
10/30/64	6.4	x	-				
10/30/64	18.6	-	x				
10/31/64	6.3	x	-				
11/2/64	6.0	x	-				
11/3/64	5.9	x	-				
11/4/64	5.8	x	x				
11/7/64	5.4	x	x				
11/13/64	4.6	x	x				
11/17/64	4.1	x	-				
11/29/64	2.5	x	x				

starts and disappears later in the topside compared to bottomside. In the following, these results are examined in the light of current theories on Spread F irregularities.

Dagg (1957a, 1957b) after finding all the earlier theories of Spread F as inadequate, suggested that a turbulent component of the electric field in the dynamo region is communicated to the F region along the conducting magnetic lines of force, thus producing inhomogeneities of ionization in the F region. Later analysis by Farley (1959, 1960) and Spreiter and Briggs (1961a, b) showed that the coupling is too weak to produce small scale irregular fields of any consequence in the F region at equatorial latitudes.

Martyn (1959) proposed that the base of the F region is essentially unstable when the region is moving upwards. A cylindrical inhomogeneity of ionization aligned along the magnetic field, in the F region would move with a velocity relative to the surrounding ionized medium given by

$$\nu = -\frac{V\epsilon}{2 + \epsilon} \tag{1}$$

where V is the velocity of the surrounding medium and $\epsilon = \frac{\Delta N}{N}$. Thus, from equation (1) it can be seen that below hmF_2, when the surrounding medium is moving upwards ($V > 0$), negative inhomogeneities ($\Delta N < 0$) in the ionization density would move into regions of higher ambient ionization density and consequently get amplified. Similarly, any positive inhomogeneity ($\Delta N > 0$) moves downward into regions of lower density and gets amplified. The situation is different when the layer is moving downwards since then inhomogeneities are smoothed out because negative inhomogeneities move into regions of lower ambient density and positive inhomogeneities into regions of higher ambient density. On the other hand, above hmF_2, conditions for amplification of inhomogeneities are reversed. They are amplified when the layer is moving downwards, since then the negative inhomogeneities move into regions of higher ambient density and positive inhomogeneities into regions of lower ambient density.

Following Martyn, the upward velocity of the F region required for the irregularities ($\Delta N < 0$) at the base of the F region to reach hmF_2 during their lifetime is calculated. The lifetime of the irregularities is the relaxation time of the region itself, given by β^{-1}, β being the loss rate of the region and according to the current understanding β^{-1} is of the order of 10^4sec. From an examination of bottomside N-h profiles, between the hours 1800 to 2000 hours LMT for the month of October 1964 obtained from Huancayo ionograms by a method due to Jackson (1956), it is found that on the average a parabolic expression of the type

$$N = Nm \left(1 - \frac{Z^2}{2.56}\right) \tag{2}$$

where z is the height measured from hmF_2 in units of scale height, taking the scale height H as 55 km at 300 km level, is a good approximation for the bottomside F region during those hours. Starting from

$$\nu = - \frac{V\varepsilon}{2+\varepsilon} \simeq \frac{V\varepsilon}{2} \text{ when } \varepsilon << 1,$$

$$\nu = \frac{dz}{dt} = - \frac{V}{2} \left[\frac{N_1 + \Delta N_1 - N}{N}\right] \tag{3}$$

substituting (1) and (2)

$$\frac{dz}{dt} = \frac{V}{2} \left[1 - \frac{2.56(N_1 + \Delta N_1)}{Nm\ (2.56 - Z^2)}\right] \tag{4}$$

Integrating this equation between Z_1 and Z_2 gives

$$\frac{Vt}{2} = Z_2 - Z_1 + (2.56 - A)\ A^{-\frac{1}{2}} \tanh^{-1} \left[\frac{A^{\frac{1}{2}}\ (Z_2 - Z_1)}{A - Z_1 Z_2}\right] \tag{5}$$

where

$$A = 2.56 \left[1 - \frac{N_1 + \Delta N_1}{Nm}\right]$$

Now taking $N_m = 9.2 \times 10^5/cm^3$ (average value obtained from the N-h profiles) and choosing arbitrarily an irregularity of strength $\varepsilon = -0.001$ the velocity V of the F region required for an irregularity situated near the base of the region ($Z = 1.55$) to reach the level of hmF_2 during its lifetime ($t = 10^4$ sec) is calculated from equation (4) to be equal to 24.3 m/sec.

From an examination of these bottomside true height profiles, it is noticed that such upward motions are not uncommon after sunset. Thus in the bottomside F region when the region is moving upwards after sunset, weak negative inhomogeneities can move into the level of hmF_2 and consequently get amplified, causing Spread F.

A complementary process has been proposed by Calvert (1963) in which the same amplification process is invoked but its operation is attributed to a descent of the neutral gas due to the cooling of the F region after sunset. According to Clemmow et.al., (1955) a "wind" of neutral gas of velocity V_w will move weak irregularities with the relative velocity

$$\nu = \frac{1}{2} V_w \epsilon \tag{6}$$

Thus, in the bottomside region, after sunset, ν is in the right direction for the amplification of the irregularities, whereas in the topside region it is in the opposite direction.

It may be that both these mechanisms are operative in the bottomside F region to produce irregularities causing Spread F. However, in the topside region, as stated earlier, on the basis of Martyn's theory, irregularities will be amplified when the region is moving downward. It is appropriate to consider here Farley's (1965) observations of the equatorial ionosphere at Jicamarca, Peru using the incoherent backscatter technique. From his figures of diurnal variation of electron density contours, it can be readily seen that the contours, following a rise after sunset, begin to descend.

Topside ionograms for the latitude range 0^o to 4^oS geomag. lat. for the hours 1800 to 0000 LMT, during the period of observation have been reduced to true height-electron density by the method due to Fitzenreiter and Blumle (1964). The resulting data is presented in the form of constant height profiles of electron density as shown in Fig. 5. It can be readily seen from this figure that these curves show a rapid fall from about 2000 hours after an initial rise. Thus, if at least part of this apparent downward motion is attributed to electrodynamic forces, the onset of Spread F in the topside region after 2000 hours can be explained as due to the amplification of the irregularities during the downward motion of the region. It is pointed out earlier that in the bottomside irregularities get amplified when the region is moving upwards. Thus as the F region after sunset first moves upwards and then begins to descend, one would expect from the foregoing discussion that Spread F starts earlier in the bottomside compared to topside. This would explain on a qualitative basis, the delayed onset of Spread F in the topside region compared to that in the bottomside.

Similar to Calvert's (1963) suggestion, a complementary process is suggested here to explain the persistence of topside Spread F in the morning hours. After sunrise, the upper atmosphere is abruptly heated. This heating must be accompanied by an adjustment in the vertical distribution of atmospheric density and thus by an upward motion of the neutral atmosphere. From equation (5), it can be seen that this motion is in the right direction for the amplification of the irregularities in the topside region, whereas in the bottomside region, this will smooth out the irregularities, in addition to the smoothing by fresh ionization due to solar radiation. Thus, in the topside region, although the fresh ionization will try to smooth out the irregularities that are present, there may be amplification of the irregularities in the morning hours. As a consequence, the phenomenon may persist in the morning hours in the topside region with reduced activity as is observed in the present investigation.

Finally, it should be pointed out that the current theories discussed here cannot account for the persistence of the Spread F irregularities throughout the night as the lifetime of the irregularities predicted by these theories is only about 10^4 sec.

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CAPTIONS FOR FIGURES

Fig. 1a	Diurnal Variation of Topside Spread F for Latitudes North of Geomagnetic Equator.
Fig. 1b	Diurnal Variation of Topside Spread F for Latitudes South of Geomagnetic Equator.
Fig. 2	Latitudinal Distribution of Topside Spread F.
Fig. 3	Kp index vs Percentage Occurrence of Topside Spread F.
Fig. 4	Diurnal Variation of Topside and Bottomside Spread F.
Fig. 5	Electron Density at Constant Altitudes in the Topside.

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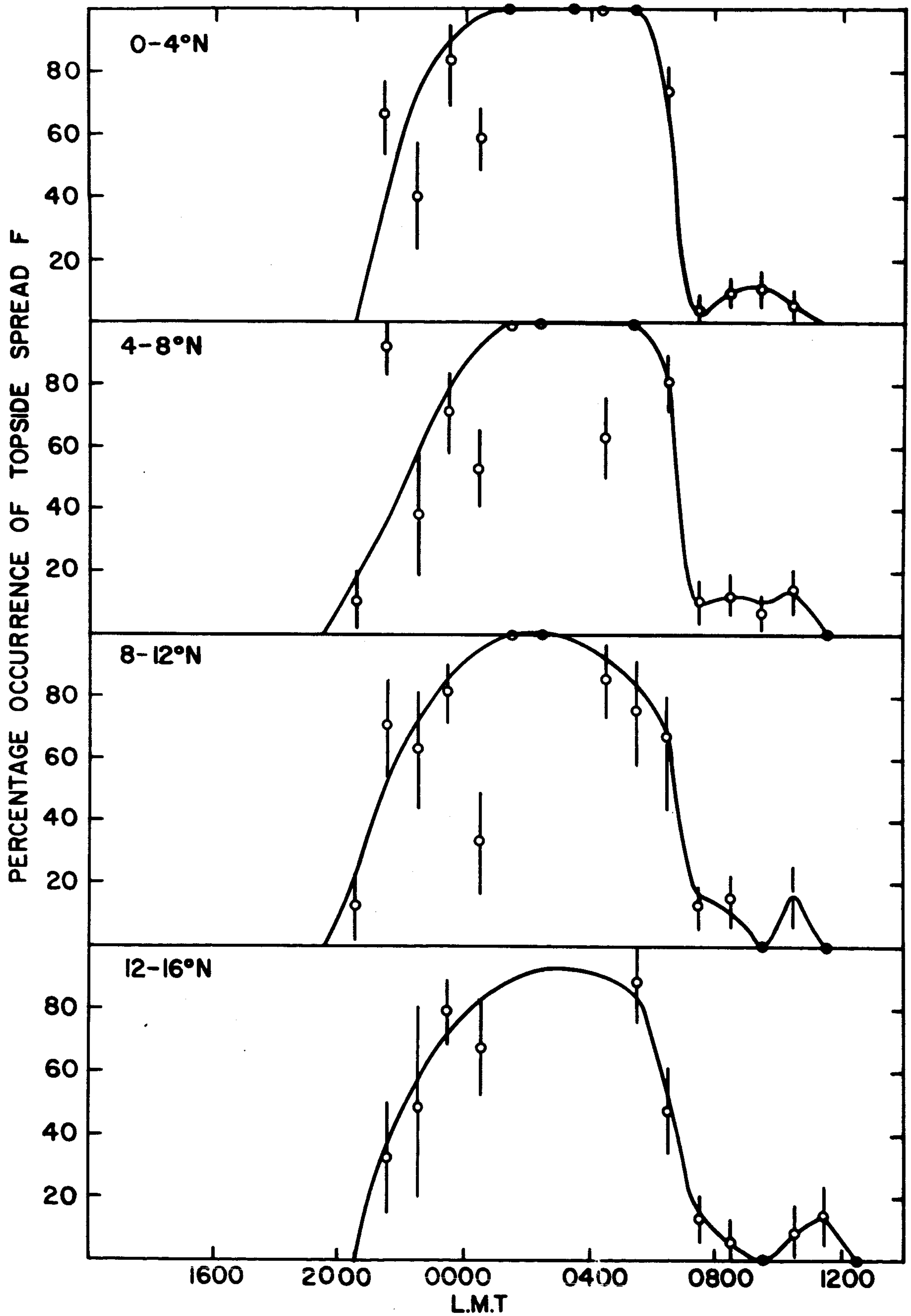
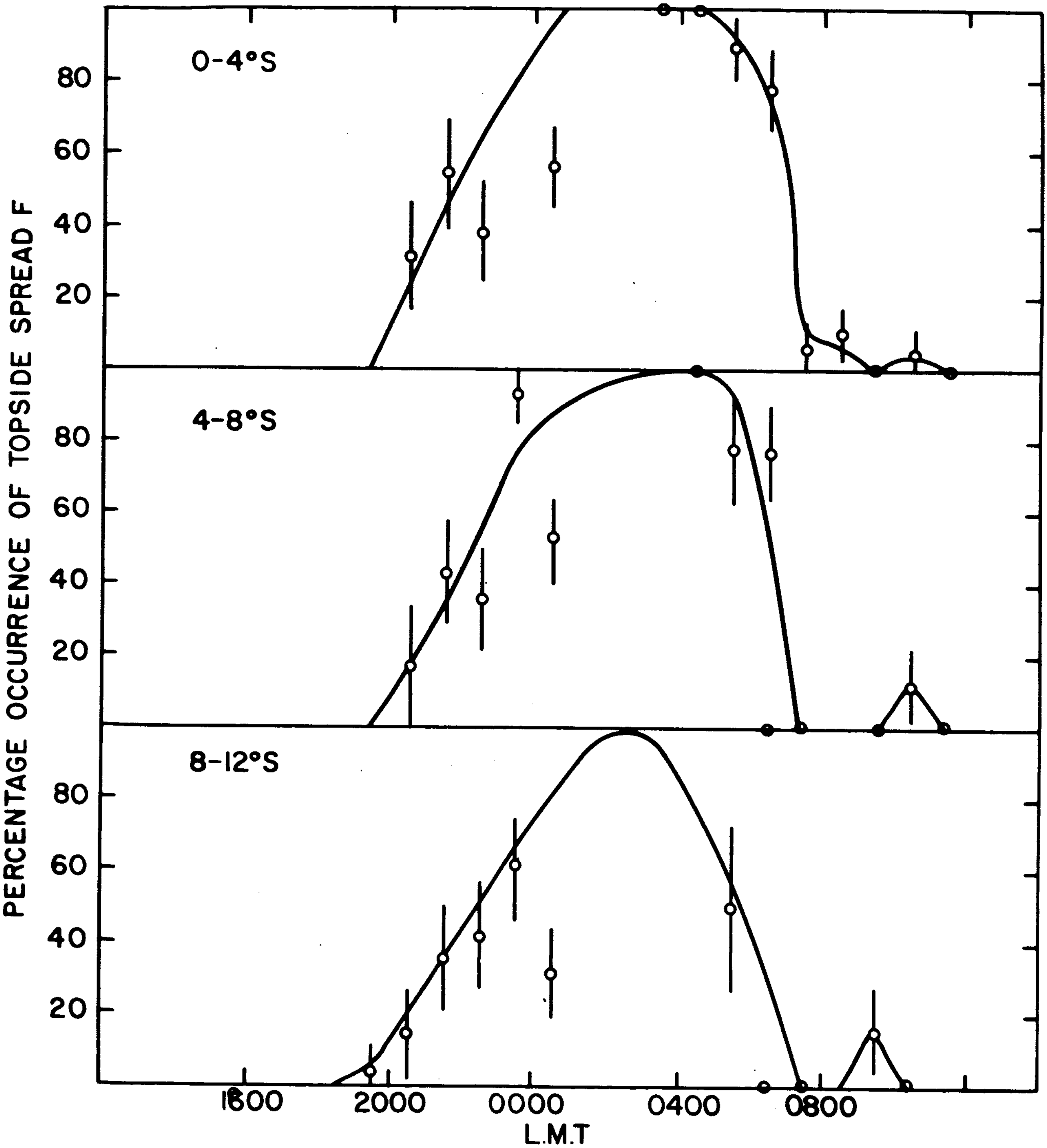

0-4°N
4-8°N
8-12°N
12-16°N
80
60
40
20
PERCENTAGE OCCURRENCE OF TOPSIDE SPREAD F
1600
2000
0000
0400
0800
1200
L.M.T



0-4°S
4-8°S
8-12°S
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PERCENTAGE OCCURRENCE OF TOPSIDE SPREAD F
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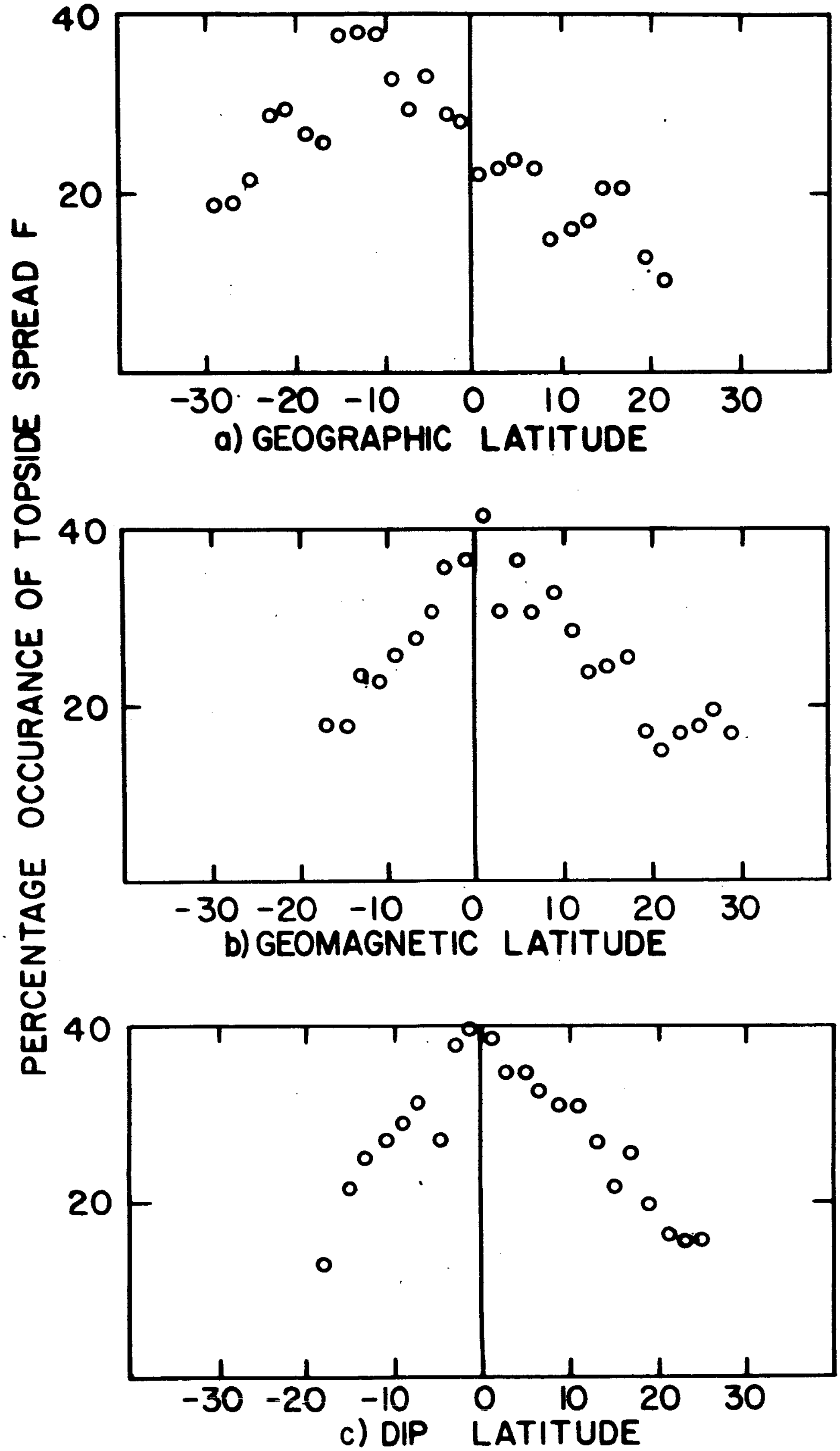
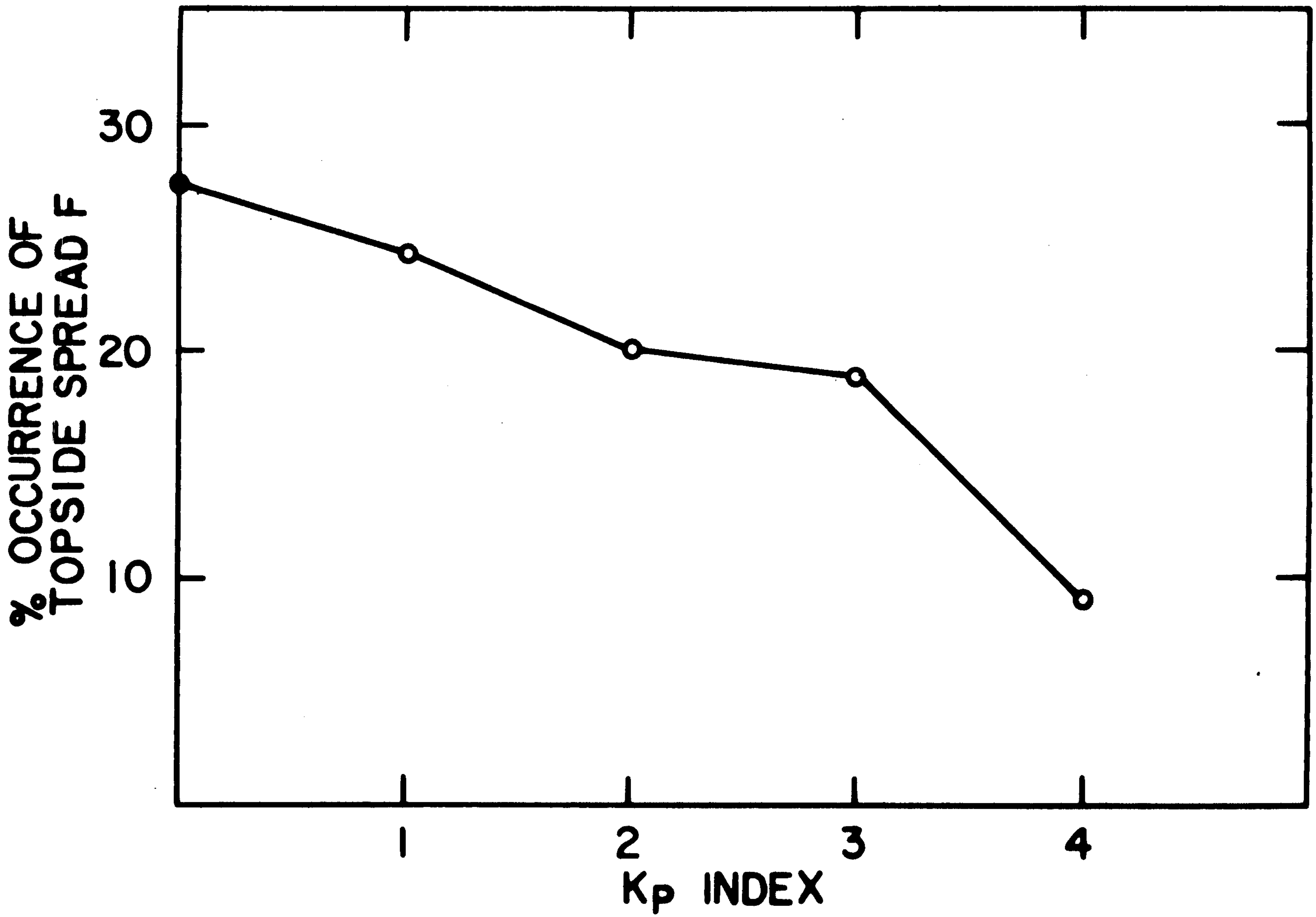
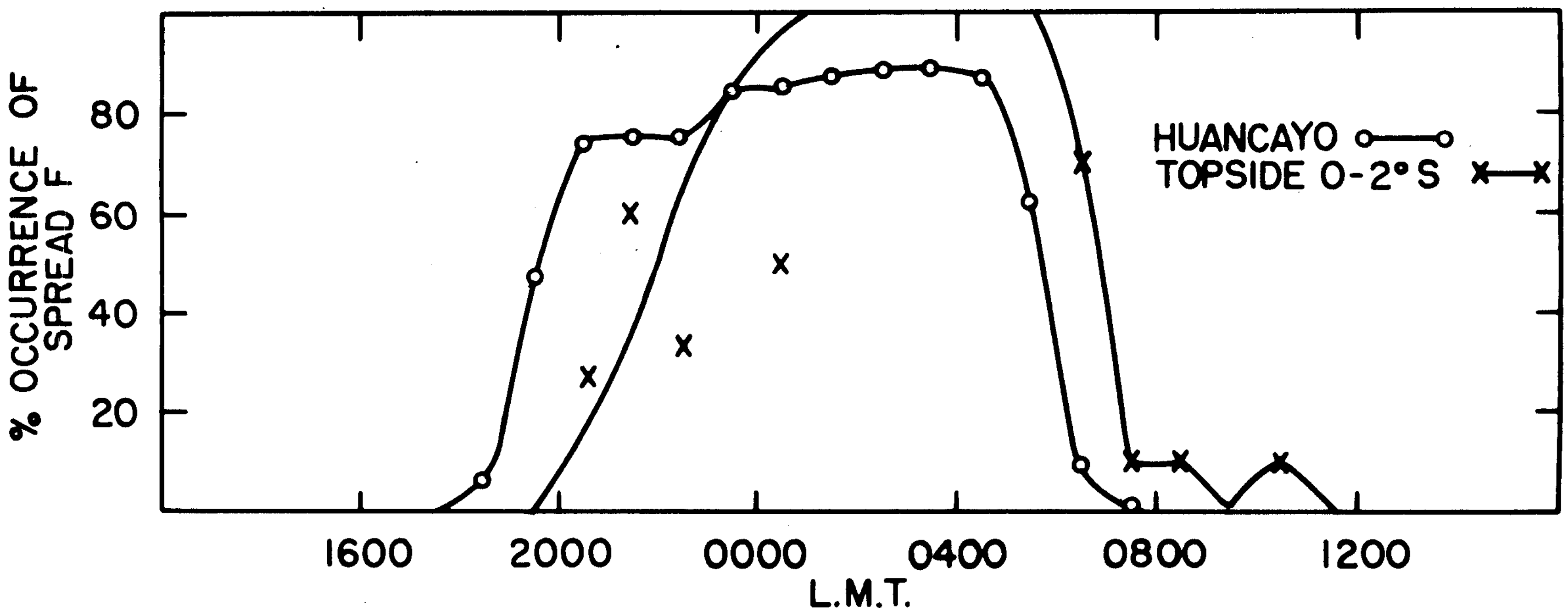
L.M.T


PERCENTAGE OCCURANCE OF TOPSIDE SPREAD F
40
20
-30 -20 -10 0 10 20 30
a) GEOGRAPHIC LATITUDE
40
20
-30 -20 -10 0 10 20 30
b) GEOMAGNETIC LATITUDE
40
20
-30 -20 -10 0 10 20 30
c) DIP LATITUDE



% OCCURRENCE OF
TOPSIDE SPREAD F
30
20
10
1
2
3
4
Kp INDEX


% OCCURRENCE OF SPREAD F
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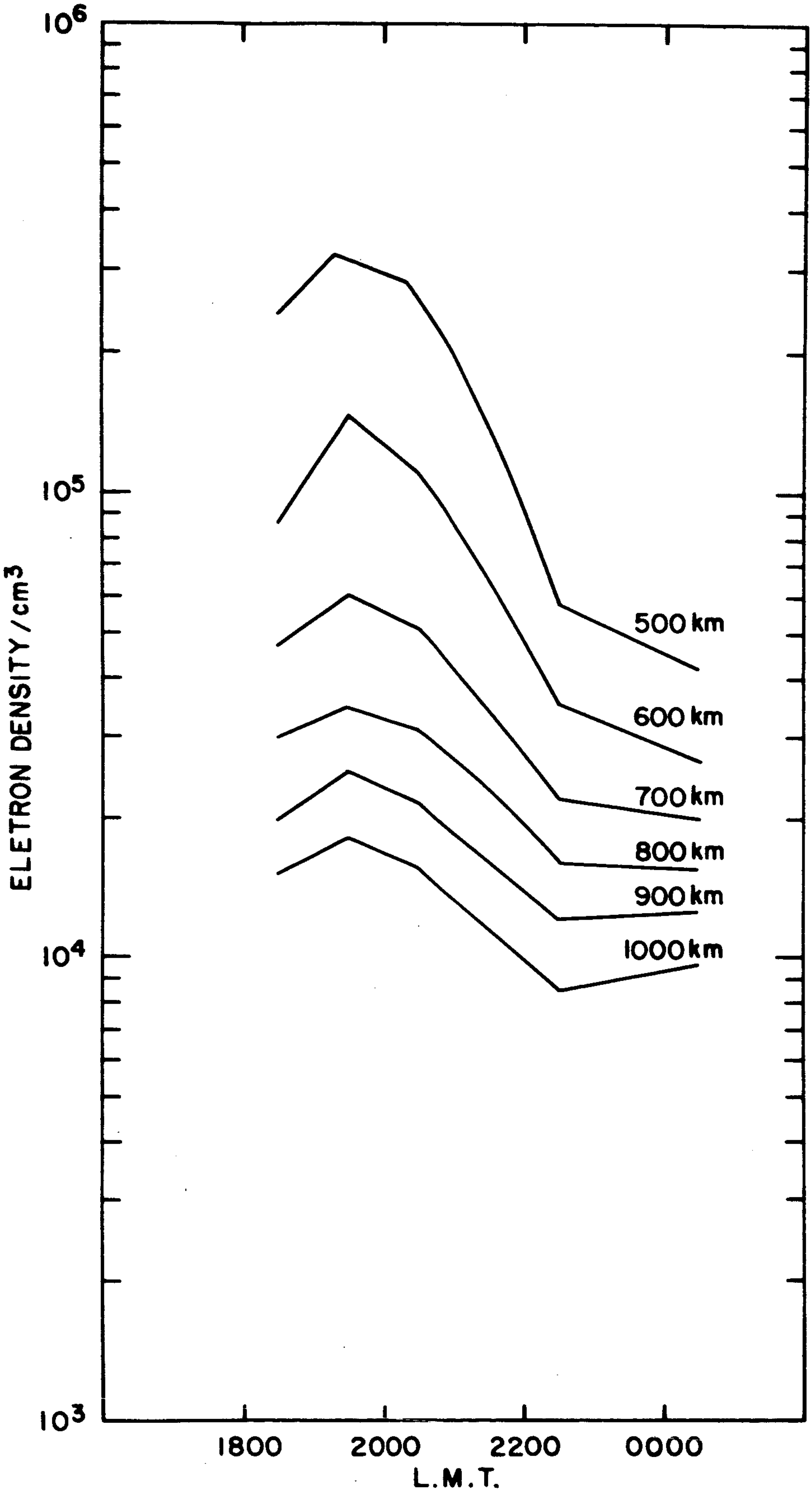
1600
2000
0000
0400
0800
1200
L.M.T.
HUANCAYO
TOPSIDE 0-2° S



10^6
10^5
10^4
10^3
ELETRON DENSITY / cm3
500 km
600 km
700 km
800 km
900 km
1000 km
1800
2000
2200
0000
L.M.T.